

The relationships between external and internal training loads in mixed martial arts

KIRK, Chris, LANGAN-EVANS, Carl, CLARK, David R. and MORTON, James P.

Available from Sheffield Hallam University Research Archive (SHURA) at:

http://shura.shu.ac.uk/32610/

This document is the author deposited version. You are advised to consult the publisher's version if you wish to cite from it.

Published version

KIRK, Chris, LANGAN-EVANS, Carl, CLARK, David R. and MORTON, James P. (2023). The relationships between external and internal training loads in mixed martial arts. International Journal of Sports Physiology and Performance.

Copyright and re-use policy

See http://shura.shu.ac.uk/information.html

- 2 Original investigation
- 3 Christopher Kirk^{1,2}, Carl Langan-Evans², David R Clark³, James P Morton²
- 4 ¹Sheffield Hallam University, Sport and Human Performance Research Group, Collegiate
- 5 Crescent, Sheffield, United Kingdom, S10 2BP
- 6 ²Liverpool John Moores University, Research Institute for Sport and Exercise Sciences, Tom
- 7 Reilly Building, Liverpool, United Kingdom, L3 3AF
- ³Robert Gordon University, School of Health Sciences, Aberdeen, United Kingdom, AB10
- 9 7AQ
- 10 Corresponding author: Christopher Kirk Email: <u>C.Kirk@SHU.ac.uk</u>
- 11 CK ORCID 000-0002-6207-027X
- 12 CLE ORCID 0000-0003-1120-6592
- 13 DC ORCID 0000-0006-6661-6137
- 14
- 15 ****This is the final, peer-reviewed, accepted manuscript which will be published in a forthcoming*
 - issue of the International Journal of Sport Physiology and Performance***
- 17

- 18
- 19
- 20
- 21

Purpose: As a multi-disciplined combat sport, relationships between external and internal 23 training loads and intensities of mixed martial arts (MMA) have not been described. The aim 24 of this study was to determine the external loads and intensities of MMA training categories 25 26 and their relationship to internal loads and intensities. Methods: 20 MMA athletes 27 (age=23.3±5.3, mass=72.1±7.2kg, stature=171.5±8.4cm) were observed for 2 consecutive weeks. Internal load and intensity (sRPE) were calculated using Foster's RPE for the session 28 overall (sRPE-TL) and segmented RPE (segRPE-TL) for each training category: warm-up; 29 striking drills; wrestling drills; Brazilian jiujitsu (BJJ) drills; striking sparring; wrestling 30 sparring; BJJ sparring; MMA sparring. External load and intensity were measured via Catapult 31 Optimeye S5 for the full duration of each session using Playerload (PLd_{ACC}) and PLd_{ACC} per 32 minute (PLd_{ACC}·min⁻¹). Differences in loads between categories and days was assessed via 33 Bayesian ANOVA (BF₁₀ \geq 3). Predictive relationships between internal and external variables 34 35 were calculated using Bayesian regression. **Results**: Session overall sRPE-TL=448.6±191.1AU; PLd_{ACC}=310.6±112AU. Category segRPE-TL range=33.8±22.6AU 36 (warm-up) - 122.8±54.6AU (BJJ drills). Category PLd_{ACC} range=44±36.3AU (warm-up) -37 125±58.8AU (MMA sparring). Neither sRPE-TL nor PLd_{ACC} changed between days. PLd_{ACC} 38 was different between categories. Evidence for regressions was strong-decisive except for BJJ 39 drills (BF₁₀=7, mod). R² range=.50-.77, except for warm up (R²=.17), BJJ drills (R²=.27), BJJ 40 sparring (R^2 =.49) and session overall (R^2 =.13). Conclusions: Whilst MMA training categories 41 may be differentiated in terms of external load, overall session external load does not change 42 within or between weeks. Resultant regression equations may be used to appropriately plan 43 MMA technical/tactical training loads. 44

45 List of Abbreviations

- 46 BF Bayes factor: the magnitude to which the data support the hypothesis over the null
- 47 hypothesis (BF_{10}) or vice versa (BF_{01})
- 48 BJJ Brazilian jiujitsu
- 49 MMA mixed martial arts
- 50 PLd_{ACC} accumulated Playerload: the external load of the training session or training
- 51 category as measured by Catapult accelerometery
- 52 PLd_{ACC} ·min⁻¹ accumulated Playerload per minute: the external intensity of the training
- session or training category as measured by Catapult accelerometery
- 54 sRPE sessional rating of perceived exertion: the internal intensity of the session as
- 55 perceived by the participant
- segRPE segmented sessional rating of perceived exertion: the internal intensity of the
- 57 training category as perceived by the participant
- 58 sRPE-TL sessional rating of perceived exertion training load: the internal load of the
- 59 session as perceived by the participant
- 60 segRPE-TL segmented sessional rating of perceived exertion training load; the internal load
- 61 of the training category as perceived by the participant

62 Introduction

Quantifying and predicting an athlete's adaptive response to training plays a key role
 in optimising performance and minimising fatigue¹. This process requires differentiation
 between external loads placed on the athlete during training and their physiological internal
 loads experienced in response². As no single method can currently accurately predict the

athlete's training dose-response³, a combination of internal and external load measurements is 67 recommended⁴. The specific contexts of certain sports can render measurement of internal and 68 external load difficult or impractical in an applied setting. An example of such a sport is mixed 69 martial arts (MMA), which is characterised by its combination of striking and grappling 70 techniques incorporated from other combat sports such as muay Thai, wrestling and Brazilian 71 jiujitsu (BJJ). In addition to being able to strike the opponent's head, torso and limbs with the 72 73 feet, hands, elbows and knees, participants are permitted to use grappling manoeuvres to attain a more dominant position in either standing or grounded phases⁵. Given these unique 74 75 movement requirements, it would be important for athlete support personnel to understand how to appropriately program the loads of the different training categories within and between 76 weeks to enable load undulations aimed at optimising performance⁶. 77

Internal loads in team sports and track and field events are traditionally quantified using 78 a range of directly measured variables including heart rate, gas analysis and blood sampling^{1,7,8}. 79 80 Direct measures have been used in simulated MMA bouts to provide an understanding of the internal effects of MMA competition⁵. The invasiveness of these methods, however, preclude 81 their regular use in training. Estimating internal load via sessional rating of perceived exertion 82 (sRPE-TL) has therefore become more common in combat sports. Previous reports 83 demonstrate sRPE-TL of boxing training sessions to range between 78-264.3 AU, with 84 taekwondo training sessions range = $200.8 - 256.7 \text{ AU}^9$. In contrast, the grappling sport of BJJ 85 sRPE-TL is reported as ~50-70 AU per session¹⁰. We recently presented novel data 86 highlighting an MMA training period consisting of static internal training load between weeks 87 (~1,500-2,000 AU). There was also an absence of statistically relevant changes in internal load 88 between days (~100-500 AU) in 6 of the 8 weeks observed. This resulted in no changes to 89 fatigue during the 8-week period¹¹. We concluded that MMA coaches may have pre-90 conceptions about which categories are most fatiguing and limit the duration of these categories 91

to spend more time on perceived lower intensity categories. This, however, results in the same
overall training load across each day and week¹¹, which may explain the absence of
physiological adaptations to MMA technical/tactical training¹².

Knowledge of MMA external training load, and how it relates to internal load, may

facilitate more appropriate programming to enable a balanced training-recovery-adaptation 96 cycle². Unfortunately, there is no accepted method of measuring external load in this 97 98 population. Proxy external load via time motion analyses (TMA) has been reported from competition, finding that participants display an activity: recovery ratio = $1:3^{13}$, with each round 99 being distinct in terms of technical actions and pacing¹⁴. No such data has been provided from 100 training due to the time-consuming nature of this method making its application impractical in 101 such an environment. Accelerometry has been suggested as a potential solution to this 102 problem¹⁵, with the Catapult Playerload metric being found to be correlated (r = .70-.84) to 103 subjective and objective internal load in other contact and non-contact sports^{7,8,16}. Summated 104 from the magnitude of changes in accelerations in the three cardinal planes¹⁷, Playerload is 105 proposed as a global score of external load and intensity¹⁸. We have previously demonstrated 106 the high reliability of Playerload in measuring isolated MMA related movements^{19,20}, in 107 addition to providing insight into the external load of simulated bouts^{21,22}. The relationship 108 between Playerload and internal load, however, has not yet been examined in an MMA training 109 environment. We did report a nearly perfect relationship between Playerload and lactate in 110 111 simulated bouts (r = .99), but a small sample size (n = 6) rendered this result non-significant²¹. Given that Playerload is capable of distinguishing between training modes and intensities in 112 boxing²³, it may be a practical method of monitoring external load and intensity in MMA 113

114 training.

95

115 Therefore, the aim of this study was to use Playerload to measure the external load and 116 external intensity of MMA training and determine whether external loads of MMA training change between days. A secondary aim was to examine to what extent Playerload relates to internal load and internal intensity. Following on previous data from our research group¹¹, we hypothesised that within week changes in external load would be absent in MMA. Based on evidence from other contact and combat sports^{7,8,16} we also hypothesised that Playerload would share a predictive relationship with internal load and internal intensity.

122 Methods

A cohort of 20 experienced (\geq 4 official MMA bouts; n=16 Tier 3 athletes, n=4 Tier 4 123 athletes²⁴) male (n=14) and female (n=6) MMA competitors (age = 23.3 ± 5.3 years; habitual 124 mass = 72.1 ± 7.2 kg; stature = 171.5 ± 8.4 cm) from 4 different MMA clubs were recruited for 125 this study following ethical approval (Liverpool John Moores University Ref: 19/SPS/007, 126 date: 1st February 2019) in keeping with Declaration of Helsinki Ethical guidelines and the 127 128 United Kingdom's Data Protection Act 2018. Participants were observed participating in their normal MMA training without intervention for two consecutive weeks, during a period when 129 130 none of the participants were preparing for competitive bouts. Training sessions were planned and conducted by 1-2 coaches at each club (total coaches = 6; 4 =full time professional MMA 131 coaches; 2 = part time MMA coaches leading session planned by their club's full time coach). 132 The content of each training session was recorded in terms of duration for the training 133 categories described in Table 1 inclusive of rest periods: 134

135

- 136
- 137

138

Warm upAny drill or session content specifically aimed at preparing participants to take part in physical activityStriking drillsAny drill consisting of repetition of coach determined striking movements (boxing and/or kickboxing) in groups for the purpose of skill enhancement and/or attainmentWrestling drillsAny drill consisting of repetition of coach determined wrestling movements (taking opponent to the ground or moving yourself from a grounded to a standing position) in groups for the purpose of skill enhancement and/or attainmentBJJ drillsAny drill consisting of repetition of coach determined submission grappling movements (either gaining a dominant grounded position or causing the opponent to submit to joint locks and/or chokes) in groups for the purpose of skill enhancement and/or attainmentStriking sparringLive rounds of open skill sparring (boxing and/or kickboxing) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.BJJ sparringLive rounds of open skill sparring (taking opponent to the ground or moving yourself from a grounded to a standing position) designed to put learnt skills into practice in a controlled, non- competitive environment.BJJ sparringLive rounds of open skill sparring (attempting to submit or attain/hold a dominant position over opponent) designed to put learnt skills into practice in a controlled, non- competitive environment to improve performance.BJJ sparringLive rounds of open skill sparring (full MMA rules) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.	Training Curregory	2
Striking drillsAny drill consisting of repetition of coach determined striking movements (boxing and/or kickboxing) in groups for the purpose of skill enhancement and/or attainmentWrestling drillsAny drill consisting of repetition of coach determined wrestling movements (taking opponent to the ground or moving yourself from a grounded to a standing position) in groups for the purpose of skill enhancement and/or attainmentBJJ drillsAny drill consisting of repetition of coach determined submission grappling movements (either gaining a dominant grounded position or causing the opponent to submit to joint locks and/or chokes) in groups for the purpose of skill enhancement and/or attainmentStriking sparringLive rounds of open skill sparring (boxing and/or kickboxing) designed to put leamt skills into practice in a controlled, non-competitive environment to improve performance.BJJ sparringLive rounds of open skill sparring (taking opponent to the ground or moving yourself from a grounded to a standing position) designed to put leamt skills into over opponent) designed to put leamt skills into practice in a controlled, non- competitive environment to improve performance.BJJ sparringLive rounds of open skill sparring (attempting to submit or attain/hold a dominant position over opponent) designed to put leamt skills into practice in a controlled, non- competitive environment to improve performance.MMA sparringLive rounds of open skill sparring (full MMA rules) designed to put leamt skills into practice in a controlled, non-competitive environment to improve performance.	Warm up	Any drill or session content specifically aimed at preparing participants to take part in physical activity
Wrestling drillsAny drill consisting of repetition of coach determined wrestling movements (taking opponent to the ground or moving yourself from a grounded to a standing position) in groups for the purpose of skill enhancement and/or attainmentBJJ drillsAny drill consisting of repetition of coach determined submission grappling movements (either gaining a dominant grounded position or causing the opponent to submit to joint locks and/or chokes) in groups for the purpose of skill enhancement and/or attainmentStriking sparringLive rounds of open skill sparring (boxing and/or kickboxing) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.Wrestling sparringLive rounds of open skill sparring (taking opponent to the ground or moving yourself from a grounded to a standing position) designed to put learnt skills into practice in a controlled, non- competitive environment to improve performance.BJJ sparringLive rounds of open skill sparring (attempting to submit or attain/hold a dominant position over opponent) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.MMA sparringLive rounds of open skill sparring (full MMA rules) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.	Striking drills	Any drill consisting of repetition of coach determined striking movements (boxing and/or kickboxing) in groups for the purpose of skill enhancement and/or attainment
BJJ drillsAny drill consisting of repetition of coach determined submission grappling movements (either gaining a dominant grounded position or causing the opponent to submit to joint locks and/or chokes) in groups for the purpose of skill enhancement and/or attainmentStriking sparringLive rounds of open skill sparring (boxing and/or kickboxing) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.Wrestling sparringLive rounds of open skill sparring (taking opponent to the ground or moving yourself from a grounded to a standing position) designed to put learnt skills into practice in a controlled, non- competitive environment to improve performance.BJJ sparringLive rounds of open skill sparring (attempting to submit or attain/hold a dominant position over opponent) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.MMA sparringLive rounds of open skill sparring (full MMA rules) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.	Wrestling drills	Any drill consisting of repetition of coach determined wrestling movements (taking opponent to the ground or moving yourself from a grounded to a standing position) in groups for the purpose of skill enhancement and/or attainment
Striking sparringLive rounds of open skill sparring (boxing and/or kickboxing) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.Wrestling sparringLive rounds of open skill sparring (taking opponent to the ground or moving yourself from a grounded to a standing position) designed to put learnt skills into practice in a controlled, non- competitive environment to improve performance.BJJ sparringLive rounds of open skill sparring (attempting to submit or attain/hold a dominant position over opponent) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.MMA sparringLive rounds of open skill sparring (full MMA rules) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.	BJJ drills	Any drill consisting of repetition of coach determined submission grappling movements (either gaining a dominant grounded position or causing the opponent to submit to joint locks and/or chokes) in groups for the purpose of skill enhancement and/or attainment
Wrestling sparringLive rounds of open skill sparring (taking opponent to the ground or moving yourself from a grounded to a standing position) designed to put learnt skills into practice in a controlled, non- competitive environment to improve performance.BJJ sparringLive rounds of open skill sparring (attempting to submit or attain/hold a dominant position over opponent) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.MMA sparringLive rounds of open skill sparring (full MMA rules) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.	Striking sparring	Live rounds of open skill sparring (boxing and/or kickboxing) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.
BJJ sparringLive rounds of open skill sparring (attempting to submit or attain/hold a dominant position over opponent) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.MMA sparringLive rounds of open skill sparring (full MMA rules) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.	Wrestling sparring	Live rounds of open skill sparring (taking opponent to the ground or moving yourself from a grounded to a standing position) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.
MMA sparring Live rounds of open skill sparring (full MMA rules) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.	BJJ sparring	Live rounds of open skill sparring (attempting to submit or attain/hold a dominant position over opponent) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.
	MMA sparring	Live rounds of open skill sparring (full MMA rules) designed to put learnt skills into practice in a controlled, non-competitive environment to improve performance.

Table 1. MMA training category definitions used during data collectionTraining CategoryDefinition

Definitions made in agreement with independent MMA coach and used previously⁷; Occasions where session sections could fit into more than one category (i.e., striking drills to set up a wrestling takedown) the session coach was asked to state which of the categories they intended the section to be more aimed towards. BJJ = Brazilian jiu-jitsu; MMA = mixed martial arts.

140

141	RPE was used to measure the internal intensity of each training category (segmented
142	$RPE = segRPE^{25}$) and the session as a whole (sessional $RPE = sRPE$) for each participant
143	individually using the Foster sRPE 0-10 scale ²⁶ 10-30 minutes after the end of the entire
144	training session ²⁷ . Internal load for each training category (segRPE-TL) ²⁵ and the session as a
145	whole (sRPE-TL) ²⁶ were calculated using the following equation:
4.4.0	

146 $\operatorname{segRPE-TL} \operatorname{or} \operatorname{sRPE-TL} (AU) = \operatorname{segRPE} \operatorname{or} \operatorname{sRPE} * \operatorname{duration} (\operatorname{mins})$

External load (Playerload = PLd_{ACC}) and external intensity (Playerload per minute = PLd_{ACC}·min⁻¹) were measured in AU via Catapult Optimeye S5 100Hz tri-axial accelerometers (Catapult Innovations, Australia) for the full duration of each training session. Units were worn in the manufacturer's harness, sized to ensure a tight fit on each participant, with the unit positioned around the T3-4 vertebrae²⁸. Each participant was assigned their own individual unit for the full duration of data collection adhering to guidelines for the use of accelerometery in sport²⁹.

154 Statistical Analyses

Inference in each of the following tests was based on the calculation of Bayes factors 155 (BF), to provide support for the hypothesis (BF₁₀) or the null hypothesis (BF₀₁) respectively. 156 Unless stated, comparisons were made using Bayesian ANOVA with a default prior r = 0.5, 157 and a default t test with a Cauchy prior as post hoc analysis. Omega squared (ω^2) was calculated 158 as the effect size. Daily training duration, sRPE-TL, PLd_{ACC} and PLd_{ACC}·min⁻¹ were compared 159 between days for Week 1 and Week 2. Daily session and category duration, segRPE-TL, sRPE-160 TL and external load variables were then averaged between the two weeks to allow between 161 days comparisons to be made. External load and external intensity differences between training 162 categories were also assessed. 163

164 Relationships between variables (training loads, training intensities, training durations) 165 were determined using Bayesian Kendall's Tau-b correlation with a stretched beta prior width = 1 and 95% credible intervals due to all variables being found to be non-parametric via Shapiro 166 Wilk test ($p \le .05$). Predictive relationships between variables were calculated using Bayesian 167 linear regression with a JZS default prior r = 0.354. Due to default priors being used, BF 168 robustness checks were performed on all tests. Where a result was found to cross a BF 169 threshold, both thresholds are reported. It should be noted, the predictive equation for Bayesian 170 171 regression is modified from frequentist regression and is expressed:

172 $y = b_0 + b_1 * x_1$

173 Where:

174 $y = \text{estimated dependent outcome variable score; } b_0 = \text{intercept constant; } b_1 = \text{regression}$ 175 coefficient; $x_1 = \text{score difference for the independent variable predictor (= independent variable - independent variable mean)}$ 177 The following thresholds were used for each BF: 1-2.9 = anecdotal; 3-9.9 = moderate; 178 10-29.9 = strong; 30-99.9 = very strong; $\geq 100 = \text{decisive}^{30}$. Though not reported in the text, 179 any result found to have BF₁₀ \geq 3 was also found to have acceptably low probability of type 1 180 error (p < .05). Correlation thresholds were set at: trivial T \leq 0.09; small T \geq 0.1; moderate T 181 \geq 0.3; large T \geq 0.5; very large T \geq 0.7; nearly perfect T \geq 0.9; perfect T = 1³¹. ω^2 thresholds 182 were set at: small $\omega^2 \geq$ 0.01; moderate $\omega^2 \geq$ 0.06; large $\omega^2 \geq$ 0.14³². All statistical tests were 183 completed using JASP 0.14.1 (JASP Team, Amsterdam, Netherlands).

184 **Results**

185 Comparisons between days and categories

Session overall displayed mean $PLd_{ACC} = 310.6 \pm 112$ AU whilst mean sRPE-TL = 186 448.6±191.1 AU. Tables displaying specific means±SD of each variable for each category per 187 day averaged and each category overall can be viewed in Supplementary File 1. As seen in 188 Figure 1 the only difference in any variable between days within weeks occurred in Week 2 189 PLd_{ACC} ·min⁻¹ (Figure 1d) due to Friday being greater than Monday (BF₁₀ = 6), Tuesday (BF₁₀ 190 = 10), Wednesday ($BF_{10} = 98$) and Saturday ($BF_{10} = 8$), respectively. Figure 2 displays training 191 duration (2a), internal load (2b), external load (2c) and external intensity (2d) per category by 192 day. 193

194 Training duration comparisons

Averaged across both weeks, less time was spent on warm-ups on Wednesdays and Fridays (post-hoc $BF_{10} = 54 - 882$) than any other training day ($BF_{10} = 190$, $\omega^2 = .25$). Striking drills duration displayed a post-hoc difference between Tuesdays and Fridays, ($BF_{10} = 6$), despite no difference between days overall ($BF_{10} = 0.9$, $\omega^2 = .7$). Training time spent on striking sparring was decisively different between days ($BF_{10} = 600$, $\omega^2 = .55$) with moderate-decisive post-hoc differences caused by Wednesday and Fridays being shorter durations ($BF_{10} = 4 - 215$). BJJ sparring had strong differences in duration between days with no post-hoc differences (BF₁₀ = 22, $\omega^2 < .01$). The longest duration MMA sparring occurred on Fridays, with decisive post-hoc differences to Mondays and Wednesdays (BF₁₀ = 35,136). No other differences in durations between days were found.

205 Internal Load Comparisons

Warm-ups caused less internal load on Wednesdays than Tuesdays and Thursdays 206 $(BF_{10} = 1,034, \omega^2 = .32, \text{ post-hoc } BF_{10} = 376-601)$. Post-hoc differences in warm up segRPE-207 208 TL were also observed between Mondays and Tuesdays and Thursdays and Saturdays (posthoc $BF_{10} = 3-4$). Daily differences in striking sparring segRPE-TL were found to be moderate 209 $(BF_{10} = 9, \omega^2 = .32)$ due to Wednesdays and Fridays displaying lower loads than Mondays and 210 Thursdays. BJJ sparring had moderate differences between days with no post-hoc differences 211 found (BF₁₀ = 6, $\omega^2 < .01$). MMA sparring was found to be distributed differently between 212 days, with the majority of sessions and greatest mean segRPE-TL occurring on Fridays (BF₁₀ 213 = 98). Despite no overall differences between days, post-hoc tests found moderate differences 214 between some days for striking drills, wrestling sparring and the session overall. 215

216

217 External load and external intensity comparisons

Warm ups caused greater PLd_{ACC} on Thursdays and Tuesdays than other days of the 218 week (BF₁₀ = 25, ω^2 = .23). BJJ drills PLd_{ACC} was moderately different between days (BF₁₀ = 219 3, $\omega^2 = .24$) due to Thursdays being moderately greater than Wednesdays (post-hoc BF₁₀ = 3). 220 Striking sparring PLd_{ACC} was decisively different between days (BF₁₀ = 820, ω^2 = .56) due to 221 Wednesdays and Fridays displaying moderate to decisive post-hoc differences to the other days 222 (post-hoc $BF_{10} = 4-372$). External load of MMA sparring was distributed more towards 223 Thursdays and Fridays (BF₁₀ = 40,516, ω^2 = .83), with moderate to decisive post-hoc 224 differences between these days and the others (post-hoc $BF_{10} = 3-2,961$). Despite no other 225 overall PLd_{ACC} differences being found, post-hoc differences were found in striking drills 226

227 (Tuesday/Friday $BF_{10} = 7$), wrestling drills (Friday/Saturday $BF_{10} = 23$) and the session overall 228 (Friday/Saturday $BF_{10} = 65$).

When using PLd_{ACC}·min⁻¹ as a marker of external intensity, decisive differences 229 between days were found for wrestling drills (BF₁₀ = 9.531, ω^2 = .49) due to Tuesdays and 230 Fridays displaying greater intensity than other days (post-hoc $BF_{10} = 3-888$). The overall 231 majority of wrestling sparring sessions, however, took place on Mondays and Wednesdays. 232 BJJ drills PLd_{ACC}·min⁻¹ was different between days (BF₁₀ = 247, ω^2 = .54) due to Wednesdays 233 external intensity being less than other days for this category (post-hoc $BF_{10} = 3-773$). BJJ 234 235 sparring PLd_{ACC} ·min⁻¹ was greater on Tuesdays than Mondays (post-hoc BF₁₀ = 6) and Wednesdays (post-hoc BF₁₀ = 10) leading to strong differences across the week (BF₁₀ = 10, ω^2 236 = .27). MMA sparring external intensity was found to be different over the week (BF₁₀ = 5, ω^2 237 = .38), with Wednesdays being lower than Fridays (post-hoc $BF_{10} = 5$). The external intensity 238 of the overall sessions differed across the week ($BF_{10} = 156, \omega^2 = .2$) with Fridays being greater 239 than all other days (post-hoc $BF_{10} = 3-36,603$), and Wednesdays being less intense than 240 Thursdays (post-hoc $BF_{10} = 3$). Post-hoc differences were found in striking sparring 241 (Tuesday/Thursday $BF_{10} = 5$) and wrestling sparring (Wednesday/Friday $BF_{10} = 3$) 242 PLd_{ACC}·min⁻¹ despite no overall differences being found for these categories. 243



Figure 1 – Mean±SD a) duration (mins), b) internal load, c) external load, and d) external
 intensity (all AU unless stated) between days within weeks. Nb. PLd_{ACC} = accumulated Playerload;
 PLd_{ACC}-min⁻¹ = accumulated Playerload per minute; sRPE-TL = sessional rating of perceived exertion training
 load



Figure 2 – Mean category a) duration (mins), d) internal load, c) external load and d) external intensity (all AU unless stated) by category between days within weeks. Nb. PLd_{ACC} = accumulated Playerload; PLd_{ACC} ·min ⁻¹ = accumulated Playerload per minute; sRPE-TL = sessional rating of perceivedexertion training load; segRPE-TL = segmented sessional rating of perceived exertion training load.

284 External load and external intensity between training categories

Differences between categories can be viewed in Figure 3. External load (3a) was decisively different between training categories with a large effect ($BF_{10} = 4.551^{e+8}$, $\omega^2 = .16$). Warm up PLd_{ACC} was lower than all other categories with the exception of wrestling sparring ($BF_{10} = 703-1.779^{e+6}$). Wrestling sparring also caused lower external load than all other categories apart from warm up ($BF_{10} = 9 - 8,698$). BJJ sparring displayed lower external load than striking drills ($BF_{10} = 3$) and MMA sparring respectively ($BF_{10} = 7$).

External intensity (3b) was also different between categories with a large effect (BF₁₀ 291 = 4.621^{e+10}, ω^2 = .20). BJJ drills caused least PLd_{ACC}·min⁻¹ of all categories (BF₁₀ = 17 -292 5.638^{e+10}). Both striking drills (BF₁₀ = 176) and wrestling drills (BF₁₀ = 498,174) displayed 293 294 lower external intensity than striking sparring. Striking sparring also produced greater external 295 intensity than wrestling sparring and BJJ sparring ($BF_{10} = 293 - 3.773^{e+6}$), though wrestling sparring was greater than BJJ sparring ($BF_{10} = 7$). MMA sparring caused more $PLd_{ACC} \cdot min^{-1}$ 296 than all other categories with the exception of striking sparring ($BF_{10} = 6-2.213^{e+11}$). 297 Differences between categories in terms of internal load (3c) and duration (3d) have previously 298 been evidenced¹¹ so have not been retested here. Data for these variables as collected for the 299 current study are displayed for complete reporting (Figure 3c and 3d). 300

301

302

303

304

305



Figure 3 – Mean±SD a) external load, b) external intensity, c) internal load (all AU) and d)
 duration (mins) of each training category. Nb. PLd_{ACC} = accumulated Playerload; PLd_{ACC}·min⁻¹ =
 accumulated Playerload per minute; segRPE-TL = segmented sessional rating of perceived exertion training
 load; differences between internal load and duration of categories not tested

Correlations between internal and external loads can be viewed in Figure 4. All MMA 312 category correlations were moderate-to-large, with the exception of BJJ related categories 313 which both displayed lower boundaries below the small threshold. Similarly, warm up and 314 session overall correlations are small-to-moderate only. The data also support predictive 315 316 relationships between PLd_{ACC} and segRPE-TL/sRPE-TL in all categories (Table 2), though this support was only moderate-to-strong for warm up and BJJ drills. In terms of internal and 317 external intensity, only three categories displayed statistically relevant correlations between 318 segRPE and PLd_{ACC}·min⁻¹, with these being small-to-moderate (Figure 4). 319



Figure 4 – Kendall's Tau-b correlations between: internal load (segRPE-TL/sRPE-TL) and external load
 (PLd_{ACC}); internal intensity (segRPE/sRPE) and external intensity (PLd_{ACC}·min⁻¹). Nb. Blue dots show
 correlations between internal load (segRPE-TL/sRPE-TL) and external load (PLd_{ACC}), with statistically relevant
 BF annotated above; Red dots show correlations between internal intensity (segRPE/sRPE) and external
 intensity (PLd_{ACC}·min⁻¹), with statistically relevant BF listed below; Individual training categories display Tau-b
 between PLd_{ACC}/PLd_{ACC}·min⁻¹ and segRPE-TL/segRPE; session overall displays Tau-b between
 PLd_{ACC}/PLd_{ACC}·min⁻¹ and sRPE-TL/sRPE. Error bars = 95% credible intervals.

(1 LUACC) II OIN INVERSION (SEGNEL TE/SKEL TE)											
Category	Intercept (b ₀)	Regression coefficient (b₁)	BF ₁₀	R ²							
Warm up	43.983	0.555	18	.167							
Striking drills	114.875	0.639	3.063 ^{e+6}	.497							
Wrestling drills	103.554	0.853	7.324^{e+11}	.738							
BJJ drills	93.44	0.331	7	.272							
Striking sparring	82.734	0.69	4,389	.560							
Wrestling Sparring	57.296	0.563	8.656^{e+8}	.746							
BJJ sparring	84.855	0.44	4,982	.491							
MMA sparring	124.997	0.984	6,901	.772							
Session overall	310.631	0.191	67	.129							

 Table 2 – Bayesian regression parameters for estimating MMA external load (PLd_{ACC}) from internal load (segRPE-TL/sRPE-TL)

Nb. Individual categories display predictive relationships between PLd_{ACC} and segRPE; Session overall displays predictive relationship between PLd_{ACC} and sRPE.

Correlations between external training load and training duration (Figure 5) were also mostly moderate-to-strong. The exceptions again were BJJ related categories (lower bounds below the small threshold), warm up and session overall (both small-to-moderate). In terms of predictive relationships, BJJ drills was the only category to not have a better than anecdotal relationship between external load and duration (Table 3). Correlations between internal load and training duration were all moderate or greater, with only the lower bounds of BJJ drills and session overall falling below the moderate threshold (Figure 5).



(PLd _{ACC}) from duration (mins)											
Category	Intercept (b ₀)	Regression coefficient (b₁)	\mathbf{BF}_{10}	R ²							
Warm up	43.983	2.002	6	.126							
Striking drills	114.875	3.331	8.834^{e+14}	.769							
Wrestling drills	103.554	4.039	1.110^{e+10}	.684							
BJJ drills*	93.440	0.622	1	.097							
Striking sparring	82.734	5.610	2.403^{e+6}	.734							
Wrestling Sparring	57.296	4.923	4.000^{e+12}	.846							
BJJ sparring	84.855	1.974	169	.362							
MMA sparring	124.997	8.168	38,381	.820							
Session overall	310.631	2.090	1,255	.186							

 Table 3 – Bayesian regression parameters for estimating MMA external load

 (PLd_{ACC}) from duration (mins)

Nb. * = Evidence for BJJ drills regression is anecdotal but shown for reference

Category correlations between internal load and internal intensity (Figure 6) were all found to be moderate with the exception of MMA sparring which was not statistically relevant. The lower bound for striking sparring also fell below the trivial threshold. External loads were found to have small-to-moderate correlations with external intensity for most categories, with the exception of striking drills, wrestling sparring and BJJ sparring which were not statistically relevant (Figure 6).





408Figure 6 – Kendall's Tau-b correlations between MMA training loads (PLd_{ACC}/segRPE-TL/sRPE-TL)409and training intensities (PLd_{ACC}·min⁻¹/segRPE/sRPE). Nb. Blue dots show correlations between external410load (PLd_{ACC}) and external intensity (PLd_{ACC}·min⁻¹), with statistically relevant BF annotated below; Red dots411show correlations between internal load (segRPE-TL/sRPE-TL) and internal intensity (segRPE/sRPE), with412statistically relevant BF annotated above; For internal load and intensity relationships, individual training413categories display Tau-b between segRPE-TL and segRPE; session overall displays Tau-b between sRPE-TL414and sRPE; Error bars = 95% credible intervals.

415

416

418 Discussion

The aim of this study was to measure the external load and external intensity of MMA 419 420 training via Playerload and determine its relationship to internal load and internal intensity. We found MMA training categories display differing external loads and intensities to each other, 421 indicating Playerload can distinguish between MMA training modes. The external load of most 422 423 training categories have moderate-very large predictive relationships to internal load. The exception to this is in BJJ related categories and session overall, both of which display small-424 to-moderate predictive relationships only. Fewer relationships were found between internal and 425 external intensities, with only wrestling drills, BJJ drills and session overall being statistically 426 relevant. Both internal and external load are related to duration, with external load correlations 427 being slightly weaker than those of internal load. Relationships between load and intensity 428 appeared similar for both internal and external variables. Exceptions to this were striking drills, 429 wrestling sparring and BJJ sparring for external variables, and MMA sparring for internal 430 431 variables, where no relationships were found. MMA training categories are distributed unevenly across the week, with low-moderate intensity, drill-based categories used more often 432 earlier in the week. High intensity, sparring categories were used most on Thursdays and 433 Fridays. Despite this, neither internal nor external training load changed between days. These 434 data provide a novel understanding of relationships between internal and external MMA 435 training variables. This understanding may be used to develop training practices that provide 436 within and between week undulations in training load, which are currently absent in this 437 population¹¹. 438

Our data show a static training load across the week. This is despite more intense sparring sessions being completed at the end of the week and coaches potentially limiting the duration of high intensity categories. Though providing evidence of purposeful session planning, this approach leads to equal training loads between sessions. This may explain the

absence of between week changes in training load and fatigue previously reported¹¹. This may 443 be rectified by MMA coaches collaborating with sport science practitioners to record the 444 Playerload and sRPE-TL/segRPE-TL of their athletes using the methods detailed here. Coaches 445 may use this information to plan microcycles based on technical and tactical requirements 446 alongside physiological needs³³. For example, a high load week may consist of more instances 447 of wrestling or sparring categories, with fewer drill-based categories. Conversely, a low load 448 449 week may only include drill-based categories and BJJ sparring. The volume of each category may be determined by choosing the desired sRPE-TL for the day or week and calculating the 450 451 category external loads and durations needed to achieve this internal load. Predicting MMA athlete's internal load from the planned external load or training category durations within each 452 session may allow overreaching and restitution weeks to occur and for pre-bout tapering to be 453 applied^{6,11}. In lieu of being able to record such data for their athletes, coaches and practitioners 454 may instead plan session content and category duration using the regression data reported in 455 Tables 2 and 3, and the means in Supplementary File 1.1. Though there would potentially be 456 differences between populations and cohorts, use of the regression equations reported here may 457 provide a starting point for coaches to estimate the expected external-internal load responses 458 to their planned training content. 459

External loads and intensities were found to differ between categories, as did the 460 strengths of the predictive relationships between internal and external load for each category. 461 BJJ related categories and striking drills all had moderate relationships between segRPE-TL 462 and PLd_{ACC}, with all other categories being large. This is similar to team sports where skill-463 based training displays a reduced relationship between internal load and accelerometer derived 464 external load in comparison to open or mixed mode training³⁴. Such disparities between 465 training modes may be caused by each category's different ambulatory requirements. Repeated 466 467 foot-ground contacts increase accelerometer readings due to ground reaction forces acting on

the torso and the unit individually³⁵. This effect is increased for whole body actions of greater 468 intensity or velocity²⁸, explaining the differences between striking drills and striking sparring. 469 Though both categories include foot-ground contacts, striking drills are performed at a lower 470 intensity¹¹ leading to lower PLd_{ACC}. Grappling-based modes, however, have very different 471 movement requirements, often with little if any ambulation occurring and a high incidence of 472 isometric actions. These modes would therefore consist of reduced PLdACC but without a 473 474 concomitant change in segRPE-TL. As an example of this effect, BJJ drills had the highest segRPE-TL amongst drill categories, but the lowest PLd_{ACC}. Striking drills show the opposite 475 476 pattern, with high PLd_{ACC} but low segRPE-TL. This is despite drill categories having similar durations. Amongst sparring categories, BJJ sparring and striking sparring have comparable 477 PLd_{ACC}, but BJJ sparring results in greater segRPE-TL with a weaker relationship to external 478 load than seen in striking sparring. Therefore, internal load of BJJ related categories may be 479 more affected by isometric contractions and physical bearing of opponent mass rather than 480 481 changes in movement. Added to this would be the mental strain of skill learning, which also cannot be measured by accelerometry but stills affects RPE^{33,36}. These different contributions 482 to training load further reinforces the need for multiple, complimentary measures in practice¹. 483 This is particularly the case for MMA's diverse skill and physiological training requirements⁵. 484

The relationship between internal and external load for session overall was found to be 485 small-to-moderate only, which contrasts to studies in ambulatory sports reporting r > .77486 between sRPE-TL and Playerload^{8,16}. PLd_{ACC} being indicative of the amount of active 487 movement time in MMA²² may explain this result. To allow analysis of the full training 488 sessions, all rest periods were included. The intermittent nature of drill-based coaching sessions 489 means natural breaks between periods of active movement occurred. This reduces changes in 490 acceleration as measured by Playerload but does not necessarily reduce sRPE-TL/segRPE-TL. 491 This finding mirrors association football, where PLd_{ACC} and sRPE-TL display a large 492

correlation (r = .79) when sRPE-TL is calculated from the number of minutes played, but 493 reduces (r = .55) when total duration of the match is used³⁷. Each full MMA session contained 494 multiple incidences where participants were being coached or taking on fluids without 495 movement. This may cause reduced external load but not internal load. Whilst internal and 496 external loads were related in all categories, this did not occur for internal and external 497 intensity. Only two training categories and session overall displayed relationships between 498 499 intensity markers. This supports previous findings of athlete internal responses varying following equivalent external stimuli², and reinforces the notion of these factors being 500 501 conceptually distinct³⁸.

External load having comparable relationships to both internal load and training 502 duration requires further investigation to determine whether PLd_{ACC} more reflects the intensity 503 of the task, or simply time on task. It may be that coaches have preconceptions of which training 504 modes are more intense and therefore limit the durations of these categories to avoid athlete 505 506 fatigue. This may cause effects of external loads of more intense categories to be masked within the data due to shorter durations. It may also be that relationships between PLd_{ACC} and segRPE-507 TL/sRPE-TL only present due to mathematical coupling caused by the shared variable of 508 duration³⁹ which is highlighted as a potential confound for training load research in general³⁴. 509 Due to this effect, the proportions to which intensity and duration contribute to training load is 510 a source of debate. Data from both rugby codes demonstrated 70-74% of training load variance 511 can be attributed to changes in duration, with intensity explaining 24-34%⁴⁰. A similar finding 512 may be indicated here due to stronger correlations between load/duration than load/intensity. 513 Internal load as represented by sRPE-TL will always have a strong relationship to duration 514 owing to the latter being the multiplier in the sRPE-TL equation²⁶. This effect appears to be 515 less for external load, as evidenced here by weaker PLd_{ACC}/duration relationships. Relatively 516 517 wide error bars also reveal more uncertainty in this relationship compared to internal

load/duration. These correlations are, however, still stronger and more consistent between
categories than those reported for external intensity/external load. As such, duration does
appear to have a greater influence than intensity on external load in MMA training.

The nearly perfect relationship between PLd_{ACC} and total active time but not inactive 521 time in MMA sparring²², alongside the differences between categories in the current study, 522 does support intensity affecting PLd_{ACC}. Unfortunately, due to the aforementioned 523 uncertainties in the strength of correlations and the potential effects of mathematical coupling, 524 the relative contributions of intensity and duration to PLd_{ACC} cannot be fully elucidated from 525 these data. If PLd_{ACC} is more reliant on duration, it may still be an acceptable global indicator 526 of overall activity, but may not be entirely sufficient for coaches to plan for the differing 527 internal responses to sessions and categories of greater/lesser intensity^{11,41}. The co-influence of 528 duration and intensity on PLd_{ACC}, therefore, needs to be examined in future duration-matched 529 studies before the use of this variable for MMA training can be fully understood. Currently, 530 531 coaches may be advised to use the data regarding category intensities reported here and previously¹¹ to inform which categories could be planned to be of long and short durations. 532 This would also enable more intense categories to be programmed alongside less intense 533 categories within sessions and between adjacent sessions. Durations of each category may then 534 be planned as suggested previously in this manuscript. 535

These results do have some limitations. The cohort were mostly Tier 3 athletes, with the training sessions planned and delivered by a small number of coaches. This may limit the generalisability of the data across populations and performance levels. The data were also limited to a two-week period of collection, meaning the stability of these findings over time is not fully known. Training load, duration and content was, however, previously found to be static over an eight-week period, with no differences between bout preparation and regular training in a similar MMA population¹¹. This may suggest that these outcomes may be robust
over different time periods and training conditions.

544 Conclusions

In conclusion, we present the external loads and external intensities of MMA training 545 sessions and modes for the first time. MMA categories are distinguished by different external 546 and internal loads, allowing coaches to plan training load distribution in advance. PLd_{ACC} has 547 a moderate-to-large predictive relationship with segRPE-TL/sRPE-TL for most MMA training 548 549 categories, which provides regression equations for use in periodised planning thus enabling overreaching and restitution weeks to be incorporated. BJJ related categories only display a 550 moderate relationship between these variables, likely due to isometric contractions and 551 552 opponent mass bearing not being reflected by accelerometry, but still contributing to RPE.

Few relationships were found between internal and external intensities, demonstrating that these are measuring different facets of the training prescription and should be considered separately. Training duration appears to have a greater effect than intensity on load. Whilst the effect of duration on internal load in MMA appears relatively strong, the relationship between duration and external load is less clear. Future studies should therefore determine the relative contributions of intensity and duration on PLd_{ACC} to fully develop its use in MMA training environments.

560 **Practical Applications**

These data support the use of the PLd_{ACC}-segRPE-TL model in monitoring the loads of MMA training sessions, which in turn may be used to plan more appropriate loading patterns within and between micro/mesocycles. Researchers should collaborate with coaches to investigate the use of this model in managing the fatigue-recovery-adaptation cycle by calculating the duration-external load-internal load relationship of individual MMA athletes. Alternatively, coaches may use the regression equation data presented here as a starting point for their training load planning. It should be noted that this would require a certain level of understanding of statistical modelling or mathematics on the part of the coaches. Accordingly, it may be appropriate for educational resources to be designed and offered to MMA coaches with the aim of developing sufficient skills in this area to use these data effectively in their training programming.

572 Statements and Declarations

The authors have no relevant financial or non-financial competing interests to report. For the purpose of open access, the author has applied a Creative Commons Attribution (CC BY) licence to any Author Accepted Manuscript version arising from this submission. The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

578 **References**

Halson SL. Monitoring training load to understand fatigue in athletes. Sports Med 579 1. 2014;44:139-47. 580 581 Impellizzeri F, Marcora S, Coutts A. Internal and external training load: 15 years on. Int 2. 582 J Sports Physiol Perform 2018. 583 584 3. Bourdon PC, Cardinale M, Murray A, Gastin P, Kellmann M, Varley MC, et al. 585 Monitoring athlete training loads: consensus statement. Int J Sports Physiol Perform 586 587 2017;12:S2-161. 588 4. Wing C. Monitoring Athlete Load: Data Collection Methods and Practical 589 Recommendations. Strength Cond J 2018;40:26–39. 590 591 592 5. Kirk C, Clark D, Langan-Evans C, Morton J. The physical demands of mixed martial arts: A narrative review using the ARMSS model to provide a hierarchy of evidence. J 593 Sport Sci 2020;38:2819-41. 594 595 596 6. Turner A. The science and practice of periodization: a brief review. Strength Cond J 2011:33:34-46. 597 598 7. Casamichana D, Castellano J, Calleja-Gonzalez J, San Román J, Castagna C. 599 Relationship between indicators of training load in soccer players. J Strength Cond Res 600

501	2013;27:369-74.
501	2015,27.507-74.

606

610

614

618

622

629

632

635

642

645

8. Scott BR, Lockie RG, Knight TJ, Clark AC, de Jonge XAJ. A comparison of methods to quantify the in-season training load of professional soccer players. Int J Sports Physiol
Perform 2013;8:195–202.

- Slimani M, Davis P, Franchini E, Moalla W. Rating of Perceived Exertion for
 Quantification of Training and Combat Loads During Combat Sport-Specific Activities:
 A Short Review. J Strength Cond Res 2017;31:2889–902.
- 611 10. Campos F, Correa JCM, Canevari VC, Branco BH, Andreato LV, de Paula Ramos S.
 612 Monitoring internal training load, stress-recovery responses, and immune-endocrine
 613 parameters in Brazilian jiu-jitsu training. J Strength Cond Res 2020.
- Kirk C, Langan-Evans C, Clark D, Morton J. Quantification of training load distribution
 in mixed martial arts athletes: A lack of periodisation and load management. PLoS One
 2021;16.
- Kostikiadis IN, Methenitis S, Tsoukos A, Veligekas P, Terzis G, Bogdanis GC. The
 effect of short-term sport-specific strength and conditioning training on physical fitness
 of well-trained mixed martial arts athletes. J Sports Sci Med 2018;17:348–58.
- 13. Coswig V, Ramos S de, Del Vecchio F. Time-motion and biological responses in
 simulated mixed martial arts sparring matches. J Strength Cond Res 2016;30:2156–63.
- Antoniettô NR, Bello F, Carrenho AQ, de Carvalho Berbert P, Brito CJ, Amtmann J, et
 al. Suggestions for professional mixed martial arts training with pacing strategy and
 technical-tactical actions by rounds. J Strength Cond Res 2019
- 630 15. Worsey M, Espinosa H, Shepherd J, Thiel D. Inertial sensors for performance analysis
 631 in combat sports: A systematic review. Sports 2019;7.
- 633 16. Svilar L, Castellano J, Jukic I. Load monitoring system in top-level basketball team:
 634 Relationship between external and internal training load. Kinesiology 2018;50:25–33.
- Bredt S da GT, Chagas MH, Peixoto GH, Menzel HJ, de Andrade AGP. Understanding
 Player Load: Meanings and Limitations. J Hum Kinet 2020;71:5–9.
- Boyd LJ, Ball K, Aughey RJ. The reliability of MinimaxX accelerometers for
 measuring physical activity in Australian football. Int J Sports Physiol Perform
 2011;6:311–21.
- Hurst HT, Atkins S, Kirk C. Reliability of a portable accelerometer for measuring
 workload during mixed martial arts. J Athl Enhanc 2014;5.
- Kirk C, Malone J, Angell P. Intra-unit reliability and movement variability of
 submission grappling external load as measured by torso mounted accelerometery. Biol
 Sport 2023;40:457–64.

650 651 652	21.	Kirk C, Hurst HT, Atkins S. Measuring the workload of mixed martial arts using accelerometry, time motion analysis and lactate. Int J Perform Anal 2015;15:359–70.
653 654 655 656	22.	Kirk C, Atkins S, Hurst HT. The pacing of mixed martial arts sparring bouts: A secondary investigation with new analyses of previous data to support accelerometry as a potential method of monitoring pacing. Hum Move 2020;21:88–96.
657 658 659	23.	Finlay MJ, Greig M, McCarthy J, Page RM. Physical response to pad-and bag-based boxing-specific training modalities. J Strength Cond Res 2020;34:1052–61.
660 661 662 663	24.	McKay A, Stellingwerff T, Smith E, Martin D, Mujika I, Goosey-Tolfrey V, et al. Defining training and performance caliber: a participant classification framework. Int J Sports Physiol Perform 2021;17:317–31.
664 665 666	25.	Haile L, GallagherJr. M, Robertson RJ. Perceived Exertion Laboratory Manual. Springer; 2016.
667 668 669	26.	Foster C, Florhaug JA, Franklin J, Gottschall L, Hrovatin LA, Parker S, et al. A new approach to monitoring exercise training. J Strength Cond Res 2001;15:109–15.
670 671 672	27.	Uchida MC, Teixeira LF, Godoi VJ, Marchetti PH, Conte M, Coutts AJ, et al. Does the timing of measurement alter session-RPE in boxers? J Sports Sci Med 2014;13:59.
673 674 675 676	28.	McLean BD, Cummins C, Conlan G, Duthie G, Coutts AJ. The fit matters: influence of accelerometer fitting and training drill demands on load measures in rugby league players. Int J Sports Physiol Perform 2018;13:1083–9.
677 678 679	29.	Malone JJ, Lovell R, Varley MC, Coutts AJ. Unpacking the black box: applications and considerations for using GPS devices in sport. Int J Sports Physiol Perform 2017;12:S2–18.
680 681 682 683	30.	Wetzels R, Wagenmakers E-J. A default Bayesian hypothesis test for correlations and partial correlations. Psychon Bull Rev 2012;19:1057–64.
684 685 686	31.	Hopkins W. A scale of magnitudes for effect sizes [Internet]. 2002 [cited 2019 28–5];Available from: http://sportsci.org/resource/stats/effectmag.html
687 688	32.	Field A. Discovering Statistics Using IBM SPSS Statistics. 5th ed. Sage; 2018.
689 690 691	33.	Farrow D, Robertson S. Development of a skill acquisition periodisation framework for high-performance sport. Sports Med 2017;47:1043–54.
692 693 694	34.	McLaren SJ, Macpherson TW, Coutts AJ, Hurst C, Spears IR, Weston M. The relationships between internal and external measures of training load and intensity in team sports: A meta-analysis. Sports Med 2018;48:641–58.
696 697 698 699	35.	Edwards S, White S, Humphreys S, Robergs R, O'Dwyer N. Caution using data from triaxial accelerometers housed in player tracking units during running. J Sports Sci 2018;:1–9.

700 701 702	36.	Robertson RJ, Noble BJ. Perception of physical exertion: Methods, mediators, and applications. Exerc Sport Sci Rev 1997;25:407–52.
702 703 704 705 706	37.	Pustina AA, Sato K, Liu C, Kavanaugh AA, Sams ML, Liu J, et al. Establishing a duration standard for the calculation of session rating of perceived exertion in NCAA division I men's soccer. J Trainology 2017;6:26–30.
707 708 709 710	38.	Jeffries AC, Marcora SM, Coutts AJ, Wallace L, McCall A, Impellizzeri F. Development of a revised conceptual framework of physical training for use in research and practice. Sports Med 2021;:1–16.
710 711 712 712	39.	Archie Jr J. Mathematic coupling of data: a common source of error. Ann Surg 1981;193:296.
714 715 716	40.	Weaving D, Dalton-Barron N, McLaren S, Scantlebury S, Cummins C, Roe G, et al. The relative contribution of training intensity and duration to daily measures of training load in professional rugby league and union. J Sports Sci 2020;38:1674–81.
/1/ 718 719 720	41.	Seiler S. What is best practice for training intensity and duration distribution in endurance athletes? Int J Sports Physiol Perform 2010;5:276–91.
721		
722		
723		
724		
725		
726		
727		
728		
729		
730		
731		
732		

733 SUPPLEMENTARY FILE 1

				_					
	Warm up	Striking drills	Wrestling drills	BJJ drills	Striking sparring	Wrestling sparring	BJJ sparring	MMA sparring	Session overall
Duration (mins)	10 ± 4.8	26.2 ± 21.7	22.4 ± 14.3	28.6 ± 8.6	10.7 ± 7.5	10.4 ± 5.6	16.2 ± 10.2	16.4 ± 6.3	76.2 ± 21.7
PLd _{ACC} (AU) ^a	44 ± 36.3	114.9 ± 88.6	103.6 ± 71.3	93.4 ± 47.4	82.7 ± 50.6	57.3 ± 30.5	84.9 ± 37.1	125 ± 58.8	310.6 ± 112
PLd _{ACC} ·min ⁻¹ (AU) ^a	5.3 ± 3.3	5.5 ± 2.1	4.9 ± 1.5	3.2 ± 1	7.3 ± 1.9	5.6 ± 1.5	4.8 ± 1.1	7.3 ± 1.6	4.5 ± 1.4
segRPE/sRPE (AU)	3.1 ± 1.3	3.6 ± 1.4	4.6 ± 1.4	4.3 ± 1.2	5.6 ± 1.7	6.6 ± 1.4	5.8 ± 1.5	7.1 ± 1.4	5.8 ± 1.7
segRPE-TL/sRPE- TL (AU)	33.8 ± 22.6	94.4 ± 88.6	103.5 ± 70.7	122.8 ± 54.6	61.3 ± 51.5	69.8 ± 45.8	92.5 ± 55.3	116.8 ± 50.1	448.6 ± 191.1*

Supplementary File 1.1 - Descriptive data for external load, internal load, external intensity, internal intensity, and duration of MMA training categories (mean±SD)

Nb. PLd_{ACC} = accumulated Playerload; PLd_{ACC} ·min⁻¹ = accumulated Playerload per minute; segRPE/sRPE = category internal intensity; segRPE-TL = segmented sessional rating of perceived exertion training load; sRPE-TL = sessional rating of perceived exertion training load; a = decisive differences between categories; * = sRPE-TL

	Mon		Tues		Wed		Т	Thurs		Fri		Sat		Sun	
	Duration	segRPE-TL/ sRPE-TL	Duration	segRPE-TL/ sRPE-TL	Duration	segRPE-TL/ sRPE-TL	Duration	segRPE-TL/ sRPE-TL	Duration	segRPE-TL/ sRPE-TL	Duration	segRPE-TL/ sRPE-TL	Duration	segRPE-TL/ sRPE-TL	
Warm Up ^{a c}	8.8 ± 4.7	25.6 ± 18.6	12.5 ± 4.2	46.8 ± 24.2	6.4 ± 2.3	16.3 ± 9.8	11.8 ± 4.8	43.7 ± 18.6	6 ± 0	22 ± 9.2	6 ± 1.4	6 ± 1.4	0	0	
N		13		17		16		12		3		2		0	
Wrestling Drills	25.6 ± 12.1	120.1 ± 70.9	17 ± 10.3	92 ± 59	20.9 ± 18.3	87.9 ± 80.1	21.4 ± 8.7	131.4 ± 73.6	0	0	27.3 ± 18.5	100.3 ± 57.8	0	0	
Ν		16		9		17		5		0		3		0	
Striking Drills	30.2 ± 25.9	84.5 ± 104	30.2 ± 21.1	131.2 ± 87.9	15.7 ± 13.5	43.7 ± 47.4	25.5 ± 23.7	92.1 ± 80.8	9.1 ± 1.6	33.5 ± 9.3	6	30	0	0	
Ν		15		19		6		10		8		1		0	
BJJ Drills	24.1 ± 10.7	95.4 ± 48.5	28.6 ± 5.8	156 ± 91.9	31.1 ± 5.9	116.2 ± 47.7	27.3 ± 13	133.6 ± 89.2	0	0	0	0	0	0	
Ν		9		5		9		7		0		0		0	
Striking Sparring ^{a d}	17 ± 6.3	92 ± 54	13.5 ± 6.4	89.3 ± 64.1	4.6 ± 3.6	21.4 ± 13.1	14.5 ± 0.7	87.5 ± 24.7	4.3 ± 3.1	27.5 ± 22.1	0	0	0	0	
Ν		10		4		5		2		8		0		0	
BJJ Sparring ^{b d}	18.3 ± 9.2	116.3 ± 71.4	12 ± 0	92 ± 6.9	13.9 ± 9.5	77.5 ± 52.1	17.3 ± 8.1	101.3 ± 29.9	60	360	45	135	0	0	
N		9		3		19		4		1		1		0	
Wrestling Sparring	11 ± 7.6	74.2 ± 55.5	13.6 ± 3.6	100 ± 23.2	8.3 ± 5.9	54.3 ± 59.9	16.3 ± 8.1	114.3 ± 75.5	10.8 ± 4.1	74.2 ± 17.9	7.3 ± 4.5	41.7 ± 27.6	0	0	
Ν		6		5		11		3		10		3		0	
MMA Sparring ^{a e}	3 ± 0	21 ± 4.2	0	0	11 ± 0	77 ± 22	17.5 ± 5	126 ± 0	20.2 ± 2.1	143.5 ± 32.6	0	0	0	0	
N		2		0		3		2		11		0		0	
Session Overall	77.1 ± 22.1	426.5 ± 156.1 *	68.1 ± 18.6	410.9 ± 156.1*	80.1 ± 22.5	466.1 ± 216.9*	74.8 ± 17	421.2 ± 157.6*	86.8 ± 28.6	616.5 ± 208.2*	63.3 ± 5.8	296.7 ± 55.1*	0	0	
Ν		26		20		20		14		11		3		0	

Supplementary File 1.2 - Mean training category duration and internal load by day

Nb. N = number of individual sessions completed in this category on this day; segRPE-TL = segmented sessional rating of perceived exertion training load; sRPE-TL = sessional rating of perceived exertion training load; * = sRPE-TL a = decisive differences in duration between days; b = strong differences in duration between days; c = decisive differences in segRPE-TL between days; d = moderate differences in segRPE-TL between days; c = very strong differences in segRPE-TL between days.

	Mon		Tues			Wed	r	Thurs		Fri		Sat	Sun	
	PLd _{ACC}	PLd _{ACC} ·min ⁻¹	PLd _{ACC}	PLd _{ACC} ·min ⁻¹	PLd _{ACC}	PLd _{ACC} ·min ⁻¹	PLd _{ACC}	PLd _{ACC} ·min ⁻¹	PLd _{ACC}	PLd _{ACC} ·min ⁻¹	PLd _{ACC}	PLd _{ACC} ·min ⁻¹	PLd _{ACC}	PLd _{ACC} ·min ⁻¹
Warm Up ^a	26.9 ± 24.5	6.2 ± 4.9	66.9 ± 41.2	5.9 ± 2.5	32.4 ± 25.3	4.3 ± 2.4	53.7 ± 30.9	5 ± 2.4	3.6 ± 0.4	2.3 ± 0.2	0	0	0	0
Wrestling Drills ^d	119.3 ± 66.9	4.9 ± 1.1	119 ± 85.8	6.3 ± 1.2	74.3 ± 68.1	4 ± 1	114. 9 ± 71.6	5.3 ± 1.5	24.2 ± 2	8.4 ± 0.7	107.1 ± 0.2	3.2 ± 0.6	0	0
Striking Drills	138.4 ± 107.3	5.5 ± 1.2	140.6 ± 76.6	5.5 ± 2.4	89.7 ± 92.3	4.9 ± 1.3	108 ± 66.8	5.6 ± 2.8	44.2 ± 20.8	6.4 ± 2.6	0	0	0	0
BJJ Drills ^b d	79.4 ± 29.6	3.2 ± 0.7	91.2 ± 21	3.5 ± 0.8	73.1 ± 20.5	2.4 ± 0.4	141.8 ± 73.7	4.3 ± 0.8	0	0	0	0	0	0
Striking Sparring ^c	109 ± 23	6.9 ± 1.5	107 ± 39.8	7.2 ± 1.1	$\begin{array}{c} 40.6 \pm \\ 41.6 \end{array}$	6.9 ± 2.4	164.6 ± 29.6	10.9 ± 0.9	41.8 ± 33.6	7.3 ± 2.2	0	0	0	0
BJJ Sparring °	73.2 ± 43.2	4.6 ± 0.9	62.6 ± 27.5	6.2 ± 0.7	87 ± 36.3	4.4 ± 1	92.1 ± 36.9	5.6 ± 0.6	0	0	113.8	1.8	0	0
Wrestling Sparring	55.7 ± 41.4	5.1 ± 1.4	67.6 ± 20	5 ± 1	56 ± 41.4	6.6 ± 1.5	67.6 ± 71.5	3.9 ± 2.1	57.1 ± 25.2	5.1 ± 1	35 ± 16.6	6.5 ± 1.5	0	0
MMA Sparring ^{c f}	24.7 ± 6.3	6.2 ± 1.6	0	0	67.6 ± 21.7	5.9 ± 1.8	124.9 ± 3.5	8.9 ± 0.3	162.3 ± 28.3	8 ± 0.9	0	0	0	0
Session Overall ^d	329.7 ± 98.5	4.6 ± 1	342. 1 ± 129.7	4.5 ± 1.7	284 ± 107.1	3.6 ± 1	322.8 ± 135.1	4.7 ± 1.4	285 ± 44.1	5.9 ± 0.8	150.2 ± 20.4	3.4 ± 0.4	0	0

Supplementary File 1.3 - Mean training category external load and external intensity by day (AU)

Nb. N = number of individual sessions completed in this category on this day; a = strong differences in PLd_{ACC} between days; b = moderate differences in PLd_{ACC} between days; c = decisive differences in PLd_{ACC} min⁻¹ between days; b = moderate differences in PLd_{ACC} between days; c = decisive differences in PLd_{ACC} min⁻¹ between days; f = moderate differences in PLd_{ACC} min⁻¹ between days; PLd_{ACC} min⁻¹ between days; f = moderate differences in PLd_{ACC} min⁻¹ between days; PLd_{ACC} min